The Effect of Palm Biodiesel Fuel on the Performance and Emission of the Automotive Diesel Engine

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ABSTRACT

This study is devoted to the performance and emission evaluation of automotive diesel engine as affected by palm biodiesel fuel utilization. The concentration of palm biodiesel used in the test was ranged from B0 (pure petro-diesel), B10, B20, B30, B50 and B100 (pure biodiesel). The engine performance was evaluated through torque, power, and specific fuel consumption, while the emission was evaluated through carbon monoxide (CO), hydrocarbon (HC), particulate matter (PM), carbon dioxide (CO_2), and NO_x pollutants. The result shows that higher content of palm biodiesel can reduce the emission of CO, HC, PM, and CO_2. It was found that the addition of biodiesel could increase the power and torque. Further more, NO_x also decreased when the content of palm biodiesel increases, which is in contrast with those generally found in the previous non palm biodiesel studies.

Keywords: Palm biodiesel, blends, diesel engine, emission, performance, Indonesia

1. INTRODUCTION

Due to the increase in international crude oil price and global concerns about the effects of fossil fuel use on the environment, in recent years, the popularity of biodiesel has increased dramatically in the world, including in Indonesia.

The effort of biodiesel development in Indonesia has in fact been made since over ten years ago. However, the activity was not given priority due to the cheap oil price in the country. Research activity was limited only in laboratory scale and performance test. Observing the continuously soaring fuel price and increasingly diminishing Indonesia's oil reserves, Indonesian government shows its seriousness in developing alternative energy, including biofuel. Various policies which support the development of this energy have been made. Among them are Presidential Regulation No. 5/2006 regarding the National Energy Policy (Perpres, 2006), Presidential Instruction No. 1/2006 regarding the utilization of biofuel (Inpres, 2006), the Indonesian biodiesel standard – so called SNI 04-7182-2006 (BSN, 2006), and the decree No. 3675K/24/DJM/2006 issued by the Ministry of Energy and Mineral Resources, that regulates the use of FAME (fatty acid methyl ester) up to the maximum of 10 percent volume of automotive diesel fuel.

Since May 20th 2006, Indonesia has formally been selling a B5 blend of biodiesel, with the trade name of BIOSOLAR, at a price equal to the subsidized automotive diesel oil. However, the increasing price of CPO in the international market and its dynamic fluctuations will make it difficult for biodiesel to compete with the (subsidized) mineral diesel fuel (Rahmadi and Aye, 2003). A higher price of biodiesel-diesel fuel blend can be accepted if it's technical, environmental and other characteristics are more advantageous than the petro-diesel ones.

Numerous studies which investigate the effect of biodiesel fuel for diesel engine have been conducted world-wide. However, specific studies based on Indonesian domestic raw materials (i.e. palm and jatropha) is very limited, especially on a scientific level.

The objective of this study is to evaluate specifically the effect of palm biodiesel on the performance and emission of the automotive diesel engine. The study was performed as a part of our main research is to assess the effect of biodiesel on air pollution levels, health and economic impact of those air pollution levels. Finally, the result could be used as a scientific reference in policy and regulation decision.

2. LITERATURE REVIEW

Biodiesel by definition is a compound of methyl ester derived from the esterification/trans-esterification process of various types of vegetable oils or animal fats. The quality of biodiesel oscillates in a wide range mainly as a function of the quality of the feedstock, the fatty acid composition of the parent vegetable oil or animal fat, the production process and post-production parameters (Gerpen, www.uidaho.edu).

The effect of various biodiesel feedstocks (coconut, soybean, rapeseed, mustard and safflower) on regulated emission has been reported by Peterson, et al., (2000). The result demonstrated that lower iodine numbers correlate closely with reduced nitrogen oxides (NO_x).

The investigation of different blends of biodiesel (obtained from soybean, rapeseed or sunflower) and diesel oil (i.e. 100%, 80%, 70%, 50%, 30%, 20% and 0% volume of biodiesel, respectively) on six cylinders direct injection diesel engine has been carried out by Carraretto, et. al., (2004). The result showed that the use of biodiesel has slightly reduced the engine performances while notably increased Specific Fuel Consumption (SFC). CO emissions was reduced, but NO_x were increased. Performance and emission can be improved by optimizing the injection system.

The comparison between fossil diesel fuel and rapeseed oil methylester (RME) with regard to exhaust gas emissions and effects of these emissions on human health and the environment has also been reported by Munack, et. al., (2001). The overall result showed that a slight disadvantage of biodiesel were found concerning NO_x and ozone precursors, but on the other hand a significant soot reduction was observed that is connected with a lower mutagenic potency of the particulate matter (PM).

Laforgia and Ardito (1995) investigate the influence of pure biodiesel and blends of biodiesel combined with 10% methanol on engine performance. The result showed a remarkable reduction in smoke emerged from both solutions. The addition of alcohol produced good results as well. Better results were obtained when the injection timing was 30% in advance of the manufacture set, thus confirming the advantage of these fuels.

The use of palm biodiesel mixed with fossil fuel for certain amount (e.g. up to 30% or B30) has significantly improved emission quality, as shown in the result of a 20,000 km road test carried out in Indonesia (Wirawan et. al., 2005). As the content of biodiesel increases, the emission reduces up to 25.35% CO, 10.82% (NO_x + THC), 42.02% particulate and 23.50% opacity compared with diesel fuel.

Moreno et. al., (1999), investigates the torque, power, specific fuel consumption, and emission of pollutant of both pure diesel fuel and by mixing it with 0%, 25%, 50%, 75% and 100% Sunflower Methyl Ester (SME). The result demonstrates that the torque and power are maintained within the same levels as when using pure diesel oil, whereas the specific fuel consumption increases within the acceptable limits. The emissions of HC and CO also decrease considerably with the mentioned mixture, together with the advantage of obtaining a concentration of NO_x slightly below that of diesel fuel.

It is clear that the performance and characteristics of engine is strongly affected by fuel quality. However, the fuel quality varies in a wide range as a function of the process, raw material properties, etc.

3. MATERIALS AND METHODS

3.1 The Test Vehicle

The performance and emission tests were conducted at the Thermodynamics and Propulsion Engine Research Center, a center within The Agency for the Assessment and Application of Technology, which focuses its work on diesel engine bench and non-stationary operation tests for performance and emissions of fuels, including biodiesel. The facility is shown in Figure 1, which consists of 3 rooms, namely the control and data management room, vehicle test room and the emission analysis room. The control and data management room is used for controlling all testing activities including collecting testing data, ventilation system, Constant Volume Sampling (CVS) System, hydrocarbon and particulate sampling system and emission analysis facilities.

The test vehicle was a 2004 built passenger car with direct injection, automatic transmission, and a 2500 cc capacity diesel engine. The engine was as it is with slight modification in its fuel delivery system for convenience of fuels changing between test runs. The chassis dynamometer (CD) which is located in the vehicle test room consists of a pair of 48 inch in diameter steel roll. The roll was connected to a DC motor. The specification of CD is as follows:

- Maximum speed : 200 km/h
- Maximum power : 150 kW
- Inertia could be tested : 454 – 2722 kg
- Room testing temperature : 5 – 40 ^{o}C

Figure 1. The arrangement of emission test on chassis dynamometer

The emission analysis system consists of 5 main divisions, namely the CVS System, the handling unit, the bag, the particulate and the hydrocarbon sampling system and the emission analyzer. The function of handling system is to control the exhaust gas circulation. The emission from CVS was collected on the bag. The particulate and hydrocarbon sampling systems are only used for a diesel vehicle test. The emission analysis system consists of a gas analyzer which functions to analyze the exhaust gas emission both from the bag or transient condition and weighing the particulate. The specification of analyzers which were used in the test is shown below.

Total Hydrocarbon Analyzer
Detector: heated flame ionization
Accuracy and repeatability: +/- 1%
Measurement range: 0-4, 0-10, 0-100, 0-400, 0-1000, 0-4000, 0-10000 ppm
Response time: 2 s at 2 L/min flow rate
Ambient temperature: 5-40^{0}C
Relative humidity: maximum 95%

NO_X analyzer
Detector: Chemiluminescent
Accuracy and repeatability: +/- 1%
Measurement range: 0-4, 0-10, 0-100, 0-400, 0-1000, 0-4000, 0-10000 ppm
Respond time: 1.5 s at 2 L/min flow rate
Ambient temperature : 5-40^{0}C
Relative humidity : maximum 95%

CO analyzer
Detector : non dispersive infra-red
Accuracy and repeatability: +/- 1%
Measurement range: 0-100, 500,1000 ppm, 1%, 5%, 10%
Respond time: 15 s at 1 L /min flow rate
Ambient temperature: 5-30^{0}C

Particulate weighing
Maximum load: 5000 mg
Readability: 0.001 mg
Time for stabilization: 10 s
Filter used: PALLFLEX-70mm

3.2 The Test Fuel

Palm biodiesel used in the experiment was produced from a 1.5 ton/day capacity biodiesel plant located at the Science and Technology Research Center (PUSPIPTEK) in Serpong, which has been constructed and operated by the Institute for Engineering and Technology System Design, The Agency for the Assessment and Application of Technology (Engineering Center–BPPT) since 2003. The tests were performed to palm biodiesel with various composition blend, ranged from B0 (pure petro-diesel), B10, B20, B30, B50, and B100 (pure biodiesel). The high quality low sulfur pure petro-diesel fuel B0(1) was used to prepare B10, B20, B30 and B50 fuel samples, while the properties of pure petro-diesel fuel which is commercially sold at public fuel pump stations B0(2) was also tested in order to consider the possibility of inconsistency in the quality of diesel fuel sold in public pump stations. The characteristics of the tested fuel are shown in Table 1.

Table 1. Characteristics of pure petro-diesel and biodiesel used in the research

No	Parameter	Unit	B0(1)	B0(2)	B100	SNI
1	Density(40°C)	kg/m^3	0.836	0.836	0.859	0.850 – 0.890
2	Kinematics viscosity (40 °C)	Mm^2/s (cSt)	5.436	4.425	4.666	2.3 – 6.0
3	Cetane number		54.5	NM	61.8	min. 51
4	Flash point	°C	101	NM	185	min. 100
5	Cloud point	°C	18	18	16	max. 18
6	Water and sediment	%-vol.	0.05	0.02	0.02	max. 0.05*
7	Sulfur content	ppm-m (mg/kg)	335	1497	3	max. 100
8	Acid number	mg-KOH/g	0.18	0.28	0.504	max. 0.8

Note : NM : Not Measured
* can be separately tested as long as sediment content maximum 0.01%-vol

All parameters of biodiesel complied with SNI 04-7182-2006 (Indonesia Biodiesel Standard). As expected, the biodiesel had a considerably lower sulfur content than diesel fuel and complied with the result of the specific gravity of biodiesel fuels study performed by Yuan et. al. (2004), the density of our test fuel is increase proportionally with the higher content of biodiesel. However, palm biodiesel viscosity is lower than diesel fuel B0(1) in contrast with the general trend of the biodiesel viscosity which is usually larger than diesel fuel (Moreno et. al., 1999). A higher value of viscosity will increases the problem in the atomization and combustion process, which can potentially form engine deposits (Knothe et. al., 2004).
All samples were tested by ECE R83 (EURO 2) for an emission test cycle method as shown in Figure 2. Fuel consumption was measured by the ECE No. 84 test method and vehicle performance was tested by the 80/1269 EEC test method.

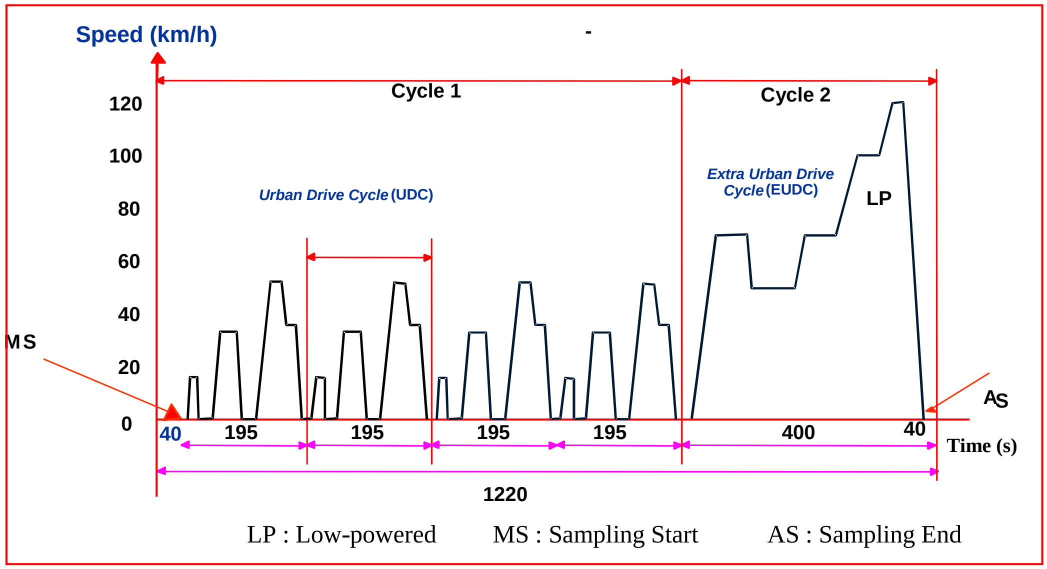

Figure 2. Emission test cycle based on ECE 83-04

4. RESULTS AND DISCUSSION

4.1 Engine Performance

Figures 3 and 4 show the curves of engine performance (torque and power VS engine speed) as the function of biodiesel – petro-diesel blend composition. As shown in figure 3, the peak power was reached at the same speed of 70 km/h. The highest peak power of 67 kW was reached by the pure petro-diesel fuel which is commercially sold at public fuel pump stations B0(2), followed by the high quality low sulfur pure petro-diesel fuel B0(1) around 62 kW, while the lowest peak power of 56 kW was shown by pure biodiesel B100. The result which is demonstrates that power exerted by pure biodiesel (B100) was lower than those by pure petro-diesel, both B0(1) and B0(2) in all speed levels is acceptable, because the calorie content of pure biodiesel is about 10% lower than calorie content of pure petro-diesel fuel.

The figure also shows that the B10, B20, B30 and B50 biodiesel blend gave higher power than the B0(1). This result was contradictive with the author's previous study which the tested palm biodiesel used for blending has lower viscosity compare to the tested petro-diesel fuel, the result showed that power and torque for biodiesel blends was higher than pure biodiesel (B100) but lower than pure petro-diesel fuel (B0) (Wirawan et. al., 2005). Therefore, it is clear that the higher power of the blending fuel compare to the power of pure petro-diesel fuel in this study could be affected by the lower viscosity value of tested pure biodiesel B100 than viscosity value of tested pure petro-diesel fuel. Fuel viscosity has impacts on injection and combustion. If fuel viscosity is high, the injection pump will be unable to supply sufficient fuel to fill the pumping chamber, which will effect to a power loss for the engine (Knothe et. al., 2004).

Figure 4 shows that torque decreased when test vehicle speed increased. Maximum torques exerted by all test fuels were reached at a speed of around a 30 to 40 km. The highest maximum torque was reached by B0(2) followed by B0(1) and the lowest torque was shown by B100, which is consistent with the peak power.

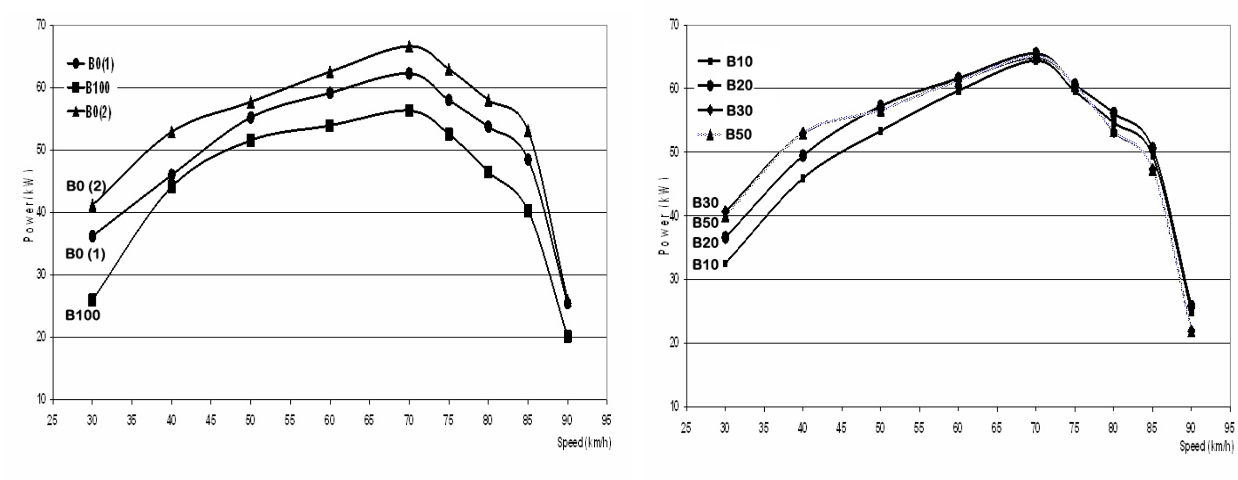

Figure 3 : Power VS Speed

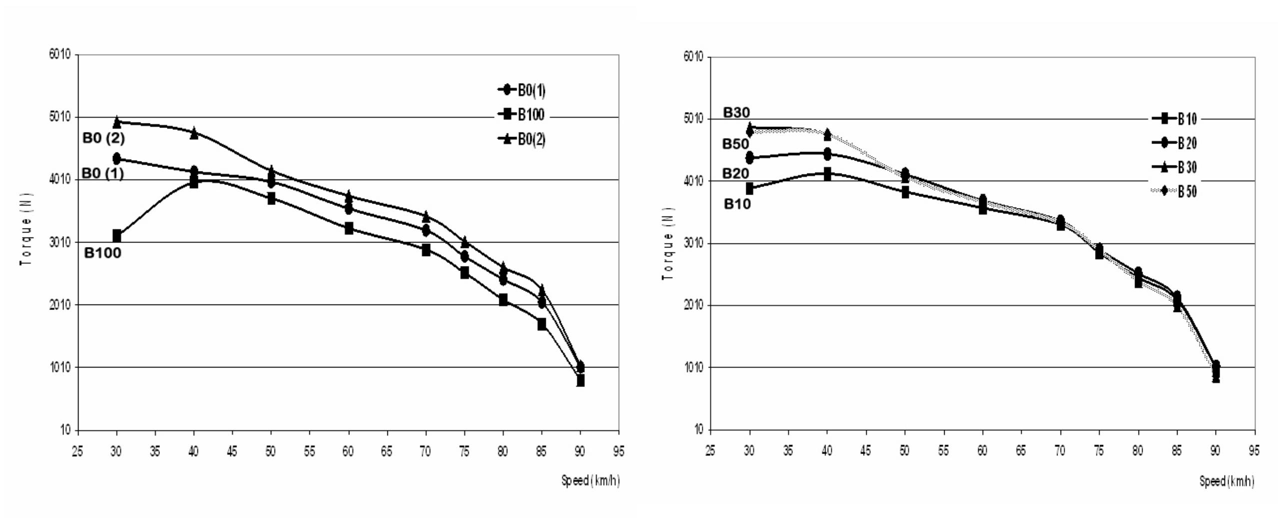

Figure 4. Torque VS Speed

4.2 The Effect of Biodiesel on Emission and Fuel Consumption

Figure 5 shows the effect of the biodiesel blend on emission of carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NO_x) and particulate from three test fuels B0(1), B0(2) and B100.

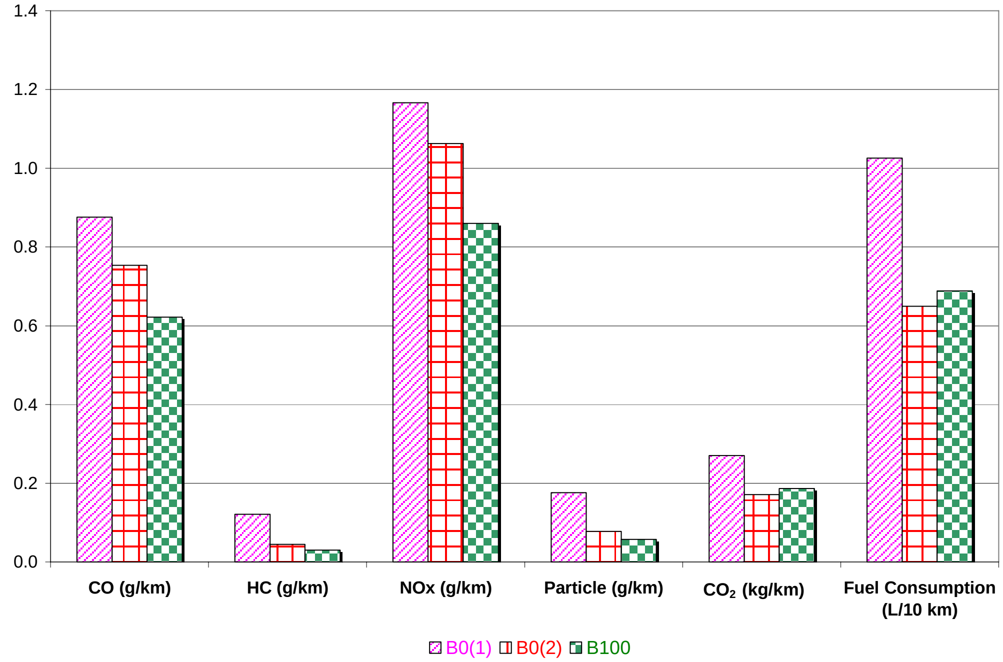

Figure 5. Emission profile

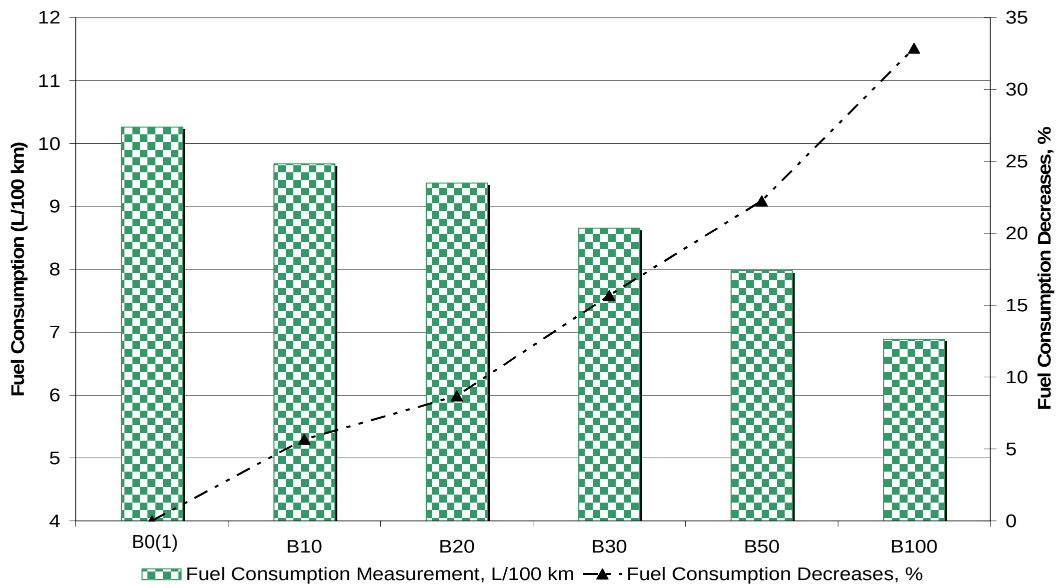

Figure 6. Fuel Consumption VS Biodiesel Blending Composition

A fuel consumption of B100 (0.69 L/10 km) was higher than a fuel consumption of B0(2) (0.65 L/10 km), but lower than B0(1) (1.03 L/10 km). Although the CO and HC emission of B0(2) was higher than B100, B0(2) released lower CO_2 emission than B100, which gives significant effect to the reduction of fuel consumption. Figure 6 shows that the reduction of fuel consumption as a function of biodiesel blend composition B10, B20, B30, B50 and B100 were 6%, 9%, 16%, 22% and 33% respectively. Those result were clearly shows a close relationship between fuel viscosity and atomization. Higher viscosity of the fuel tends to reduce the quality of fuel atomization, which could potentially give impacts to the higher emission and fuel consumption.

The effect of biodiesel on the reduction of exhaust gas emission is shown in Figure 7. The figure demonstrates that the exhaust gas emission decreased linearly with the increasing concentration of the biodiesel blend. The reduction in particle and HC emission was swifter than other emissions. Particle emission was found to reduce sharply on 10% blend of the biodiesel (B10), while the reduction of HC emission started to reduce sharply on 20% biodiesel blend (B20).

The distinct influence of sulphur content in diesel fuel on particulate emissions has been investigated by Merkisz, et.al., (2002). As expected, their result showed that the highest PM emission was obtained at the highest sulphur content in diesel fuel. The reduction of PM emission is depend on the value of sulphur content in the fuel. For fuel with lower sulphur (350 and 50 ppm) content almost the same PM emission level, but for fuel with higher sulphur (2000 ppm) content about 20% higher PM emission than lower sulphur diesel fuel.

B0(2) has higher sulfur content (1479 ppm) than B0(1) (335 ppm), but as showed on figure 5, PM emission of B0(2) was lower than B0(1). This slightly contradictive result demonstrated that the lower viscosity value of B0(2) (4.425 cSt) than the viscosity value of B0(1) (5.436 cSt) is more effective to the reduction of PM emission compare to the effect of lower sulfur content value.

CO and NO_x emissions were also reduced although not as sharp as the reduction of particle and HC emission. Lower NO_x emission at higher biodiesel blend concentration is contradictive with those generally found in previous non palm biodiesel studies. The formation of NO_x depends on the combustion temperature and oxygen content in the mixing combustion product. Biodiesel blend fuel has a faster ignition ability, increase the combustion room temperature and pressure, which would finally stimulate the NO_x formation. Nearly all cited studies report that biodiesel-fuelled engine has a slight increase of NO_x emission (Mittelbach and Remschmidt, 2004).

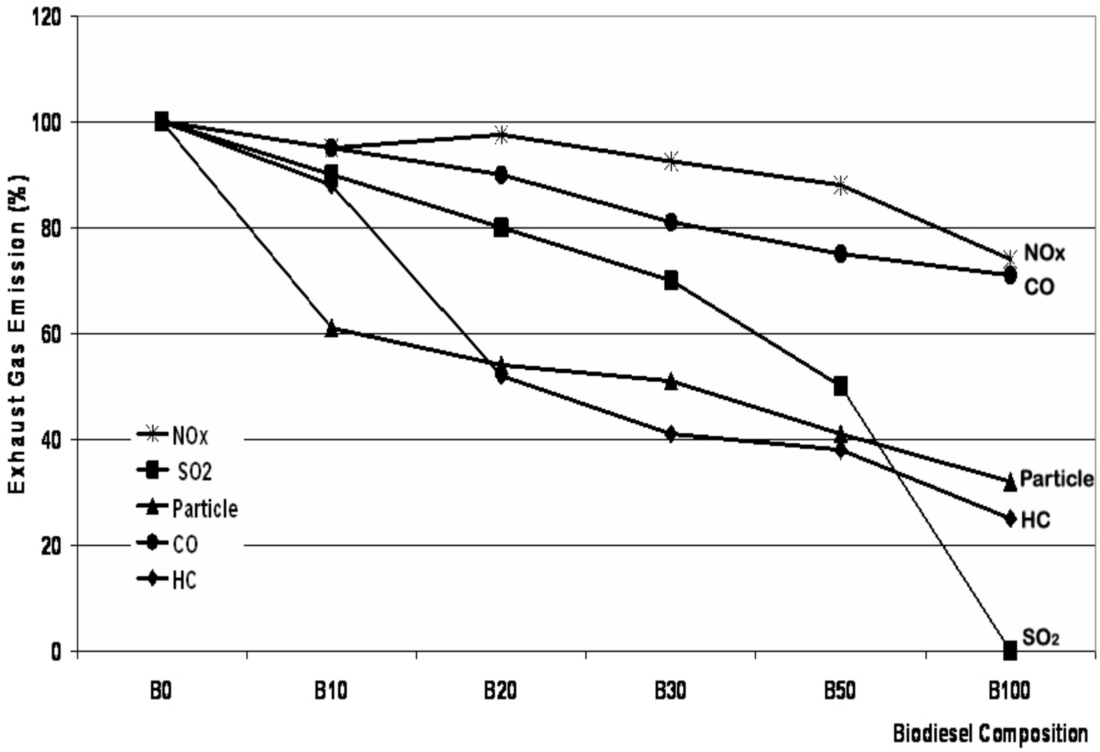

Figure 7. The effect of biodiesel on exhaust gas emission

Chemical and physical properties of the fuel, such as cetane number, also determine the NO_x emission content. There is a strong link between increasing cetane numbers and reducing NO_x emissions, but the response varies from engine to engine (Sharp (1996) in Peterson et. al., 2000). Generally, the formation of NO_x emission is very complex, which depends on fuel, engine technology, and test cycle factors. The use of the palm biodiesel, application of EURO II cycle test method, and utilization of the modern common rail engine technology, could yield in the decrease in NO_x emission.

Table 2 shows that the emission of CO and particle for blend biodiesel has met the Euro II regulation. However, it is found that NO_x + HC emission is still higher than maximum Euro II value. This is because NO_x emitted from B0(1) and B0(2) were too high compared to the Euro II regulation. Meanwhile, pure biodiesel (B100) has met the Euro II emission standard for all CO, particle as well as for NO_x + HC emissions. The increase in the NO_x emission can be mitigated by tuning the ignition time to prevent temperature and pressure increase of temperature and pressure (Knothe et. al., 2004).

Table 2. Emission of biodiesel blend as compared to Euro II regulation

Emission (g/km)	Fuel Type							Maximum (Euro II)
	B0(1)	B0(2)	B10	B20	B30	B50	B100	
HC	0.121	0.045	0.106	0.063	0.051	0.043	0.031	
NO_x	1.167	1.062	1.107	1.138	1.079	1.031	0.860	
NO_x + HC	1.288	1.107	1.213	1.201	1.13	1.074	0.891	0.9 g/km
CO	0.876	0.754	0.831	0.790	0.707	0.656	0.622	1.0 g/km
Particle	0.176	0.077	0.108	0.095	0.090	0.072	0.057	0.1 g/km

5. CONCLUSIONS

Investigation on engine test bench has been carried out to obtain comparative measurement of engine performance (torque, power, specific fuel consumption) and emission of pollutants, and to evaluate the behavior of a diesel engine running on palm biodiesel blend.

The emission of CO, HC and particle decreased considerably with the increase in biodiesel blend. The reduction in particle emission was very sharp at 10% blend (B10), while the sharp reduction in HC emission started at 20% blend (B20). The results also shows lower NO_x emission as well as higher torque and power for biodiesel blend compare to that of pure petro-diesel fuel. This result could be as a consequence of the properties of tested palm biodiesel, which has higher cetane number and lower viscosity value compared to the petro-diesel fuel sample.

6. ACKNOWLEDMENT

The authors would like to express high appreciation to the Ministry of Research and Technology, Indonesian state owned oil company PERTAMINA, PT. Toyota Astra Motor, Propulsion Engine Research Center, BPPT (BTMP - BPPT) and the Institute for Engineering and Technology System Design and BPPT (Engineering Center–BPPT) for all valuable support given to this research.

7. REFERENCES

BSN (National Standard Agency).2006. Indonesian National Standard on Biodiesel: SNI 04-7182-2006.

Carraretto, C., A. Macor, A. Mirandola, A. Stopatto and S. Tonon. 2004. Biodiesel as alternative fuel: Experimental analysis and energetic evaluations. In *Energy* 29:2195 - 2211.

Gerpen, J. V. Biodiesel Production and Fuel Quality. www.uidaho.edu/bioenergy/ biodieselED/publication.

Inpres (Presidential Instruction) No. 1. 2006. Provision and Utilization of Biofuel as Other Fuel. Jakarta. Indonesia.

Knothe, G., J. V. Gerpen and J. Krahl. 2004. In *The Biodiesel Handbook*. AOCS Press, Illinois.

Laforgia, D. and V. Ardito, V. 1995. Biodiesel fueled IDI engines: Performances, emissions and heat release investigation. In *Bioresource Technology* 51:53-59.

Merkisz, J., M. Kozak, P. Bielaczyc, A. Szczotka. 2002. An Investigation of Influence of Diesel Fuel Sulphur Content on Particulates Emissions From Direct Injection Common Rail Diesel Vehicle. Journal of KONES Internal Combustion Engines, No. 3 – 4 ISSN 1231 – 4005.

Mittelbach, M. and C. Remschmidt. 2004. *Biodiesel: The comprehensive handbook*. 1st Ed". Boersedruck Ges.m.b.H. Vienna.

Moreno, F., M. Munoz and J. Morea-Roy. 1999. Sunflower Methyl Ester as a Fuel for Automobile Diesel Engines. In *Transaction of the ASAE* 42(5):1181-1185.

Munack, A., O. Schroder, J. Krahl, and J. Bunger. 2001. Comparison of Relevant Exhaust Gas Emissions from Biodiesel and Fossil Diesel Fuel. In *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development.* Manuscript EE 01 001. Vol.III.

Perpres (Presidential Regulation) No.5. 2006. National Energy Policy. Jakarta. Indonesia.

Peterson, C. L., J. S. Taberski, J.C. Thompson and C.L. Chase. 2000. The Effect of Biodiesel Feedstock on Regulated Emission in Chassis Dynamometer Test of a Pickup Truck. In *Transaction of the ASAE* 43(6):1371-1381.

Rahmadi, A. and Lu Aye. 2003. Biodiesel from palm oil as an alternative fuel for Indonesia: opportunities and challenges. In *41st Annual Conference of the Australian and New Zealand Solar Energy Society. Destination Renewables: from Research to Market,* Melbourne, Australia, 26-29 November.

Sharp, C. 1996. Emission with ethyl and methyl esters of biodiesel. *In Commercialization of Bodies: Environmental and Health Benefits. Moscow. Idaho: National Institute for Advanced Transp*. Tech. University of Idaho.

Wirawan, S. S., M. Nuramin and M.D. Shalikah. 2005. In *The report on the 20.000 km road test of biodiesel B30 on diesel engine passenger car*. BPPT.

Yuan, W., A. Hansen, and Q. Zhang. 2004. The Specific Gravity of Biodiesel Fuels and Their Blends with Diesel Fuel. In *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development.* Manuscript EE 04 004. Vol. VI..